interference power into a MLS receiver as –130 dBm to prevent this from occurring.[216] NTIA subtracted 4 dB from the ICAO threshold "to partition the UWB interference into the link budget," resulting in NTIA's maximum permissible UWB interference level of –134 dBm, a level that is 22 dB below the thermal noise floor of the MLS receiver and 31 dB below the sensitivity of the MLS receiver. NTIA employed a 5-dBi gain antenna, the maximum available to the aircraft at an angle of about 30 degrees below the horizontal.

143. Our analysis of the MLS focused on two approaches. First, the receiver noise floor is –112 dBm, and the ICAO maximum interference level is –130 dBm. This interference level is 18 dB below the noise floor and 27 dB below the sensitivity level of the receiver. An interfering signal at 18 dB below the noise floor would result in an increase to the MLS receiver noise floor of only 0.07 dB. Such a small increase in the noise floor is not detectable by the receiver or by measurement instrumentation. We believe that employing the ICAO value as a protection criterion is overly conservative for this system. Further, we do not agree with the comments from Rockwell stating that the 4 dB additional safety margin added by NTIA is inadequate for MLS operation in a Category III approach. Rockwell did not provide any justification for an additional safety margin. Indeed, we believe that the ICAO threshold, even without the 4 dB additional safety margin applied by NTIA, is too conservative. Second, we note that NTIA calculated that harmful interference would be caused to MLS from a UWB transmitter operating at the Part 15 general emission limits at a maximum separation distance of 160 meters. We also note that the expected operating range of the MLS system is 43 km at an altitude of 20,000 feet. There is little likelihood that at this range from the MLS transmitter the aircraft will be within 160 meters of a UWB transmitter. As the aircraft approaches the ground, it will come much closer to the MLS transmitter, increasing the level of the received signal to the point that the MLS signal would be considerably greater than the signal level from a UWB transmitter operating at the Part 15 general limits.[217] NTIA also stated that its calculations were based on the aircraft being at a height of 30 meters. At this height, the aircraft would be near the MLS transmitter, whose signal level would override any potential interference.

144. *TDWR.* These radars operate in the 5600-5650 MHz band and provide measurements of gust fronts, microbursts, and other weather hazards at for improving safety operations at major airports in the United States. They are located within 24 kilometers (15 miles) of airports and need to have a clear line-of-sight (LOS) at the runway to observe weather phenomena for aircraft approaches and landings. Indoor UWB operation is the only UWB operation not directly protected by the proposed limits. The proposed UWB EIRP level for this band is –41.3 dBm which is 8 dB above the calculated EIRP. To achieve the required protection for the TDWR, a UWB located in a 30-meter building would have to be located 1370 meters away. Given the 0.2° minimum elevation angle of the antenna mainbeam, the beam would only be 5 meters above the horizon. The building itself would at least partially obstruct the 3 dB beamwidth of the mainbeam and be the limiting factor along the given azimuth and not the UWB's EIRP. An elevation angle of greater than 1.25 degrees is required to clear a 30-meter obstacle at a distance of 1370 meters. Therefore, the geometry of the TDWR is the limiting factor for this scenario, not the EIRP of the UWB.

[216] . International Standards and Recommended Practices Annex 10 to the Convention of International Civil Aviation, Volume 1 (Radio Navigation Aids) Fifth Edition, July 1996.

[217] In order for the aircraft to be within 160 meters, horizontal, from the UWB transmitter at a receive angle of 30 degrees, as employed by NTIA in its calculations, the aircraft would be less than 93 meters above the ground.

Table 7. Maximum UWB EIRP for UWB Use Indoors

System	Frequency (MHz)	Maximum UWB EIRP (dBm/MHz) UWB Indoors 2 m height	Maximum UWB EIRP (dBm/MHz) UWB Indoors 30 m height	Average Building Attenuation Losses [218] (dB)
DME, Interrogator	960-1215	-38	Not Applicable[219]	9
DME, Transponder	1025-1150	-55	-48	9
ATCRBS, Transponder	1030	-35	Not Applicable	9
ATCRBS, Interrogator	1090	-22	-35	9
ARSR-4	1240-1370	-52	-73	9
SARSAT	1544-1545	-60	-57	9
ASR-9	2700-2900	-37	-57	9
NEXRAD	2700-2900	-33	-67	9
Marine Radar	2900-3100	-34	-45	12
FSS, 20 degrees	3700-4200	-24	-30	12
FSS, 5 degrees	3700-4200	-39	-65	12
CW Altimeters	4200-4400	37	Not Applicable	12
Pulsed Altimeters	4200-4400	26	Not Applicable	12
MLS	5030-5091	-42	Not Applicable	12
TDWR	5600-5650	-23	-51	12

145. The above table reflects NTIA's calculation of the maximum signal levels that could be permitted for UWB devices operated indoors. The possibility of restricting most applications of UWB technology to indoor use but imaging and vehicular radar applications was not considered in the NTIA analysis because it was not specifically proposed in the *Notice*. Thus, the constraints NTIA's analysis originally concluded were necessary to protect government receivers from outdoor use of UWB devices must be reformulated to account for the indoor use of UWB devices and the inherent additional expected propagation attenuation. This is done by simply adding a term for the value of expected building attenuation as a function of frequency to the link budget analysis model described earlier. The column on the far right contains the average building attenuation factor. NTIA analyzed UWB devices operating in-doors at heights of 2 meters (roughly equivalent to ground level) and 30 meters (roughly equivalent to the tenth floor in a typical suburban, office building) and calculated the maximum allowable UWB EIRP. The building attenuation level was subtracted from the values NTIA obtained in Table 6 to obtain the indoor limits at a 2 meter height. The results of the NTIA analyses are summarized in Table 7.

146. *UWB Interference due to Peak Emission Levels.* NTIA also performed a limited analysis of potential interference to SARSAT and FSS stations due to the peak level of the UWB transmitter. However, NTIA did not consider the proposed limits on peak power levels in the *Notice*, since their measurements did not show a need for such limits for analog systems and only very limited

[218] NTIA Report 95-325, Building Attenuation, at pg. 43.

[219] "Not Applicable" indicates that the particular scenario would involve an airborne receiver at the same altitude as a UWB transmitter, which should not occur.

measurements were made on digital systems. No conclusion can be made from the peak power analysis due to the non-linear nature of the digital systems, unique error correcting schemes, and unknown characteristics of individual UWB systems operating in these bands. The actual impact to a digital wideband system from the peak power received from a UWB device will depend on many receiver parameters not generally available such as modulation scheme, and bit error rates. As a result, the peak values NTIA used for its analysis are far in excess of the levels the Commission proposed in the *Notice*.[220] Consequently, we do not envision interference problems from peak emissions from UWB devices if the peak power limits proposed in the *Notice* are embraced.

3. U.S. Department of Defense Analysis of Interference to the SGLS

147. DOD provided a mathematical analysis of possible interference from UWB operation to its Space-Ground Link Subsystem (SGLS) at 2.2-2.3 GHz.[221] DOD applied free space attenuation without intervening objects, assumed a noise-like UWB emission, and applied SGLS receive antenna gains ranging from 6 to 26 dB corresponding to antenna elevation angles ranging from 20 to 3 degrees. Interference was defined with I/N ranging from +17.5 dB to –5.4 dB. It calculated minimum separation distances ranging from 19 meters to 1.522 km.

148. Few details were included with the DOD analysis. We do not agree that it is appropriate to use free space analysis or to assume the lack of intervening objects in determining propagation attenuation. We also do not believe that these DOD satellite receive stations will be located in areas were UWB devices would be sufficiently close to cause interference problems, especially with the operational constraints we are adopting in this proceeding. Similarly, as with the SARSAT and FSS stations, these antennas will not be directed at buildings or other structures that would block reception of the satellite transmissions.

4. ARRL Analysis of Noise Floor Increase in Amateur Radio Bands

149. The ARRL presented analyses of potential increases in the noise floor in the Amateur Radio Service frequency bands at 420-450 MHz (420 MHz) and 2400-2450 MHz (2450 MHz). ARRL performed calculations to show that an amateur radio receiver operating in the 420 MHz band, using a 20 dBi receive antenna gain and a receiver bandwidth of 1 kHz would experience a 56.5 dB increase in the noise floor at a distance of 30 meters from an UWB transmitter operating with an average EIRP of –80 dBm/Hz (0 dBm/100 MHz). Similar calculations were performed showing that an amateur radio receiver operating in the 2450 MHz band using a 0 dBi or a 20 dBi receive antenna gain and a receiver bandwidth of 1 kHz would experience a 11.4 and 31 dB increase, respectively, in the noise floor at a distance of 30 meters from a UWB transmitter operating with an average EIRP of –90 dBm/Hz (0 dBm/GHz).[222] Additional calculations showed that the increase in the receiver noise floor did not change if the receiver bandwidth was increased from 1 kHz to 10 kHz or from 1 kHz to 50 MHz.[223]

150. We find that ARRL's calculations overestimate the potential increase in the noise floor to amateur radio receivers from UWB devices. As an initial matter, the use of the thermal noise floor of a receiver is not a reasonable approach for evaluating whether or not harmful interference may occur. The thermal noise floor represents the minimum signal level that can be received under ideal conditions. In

[220] The primary effect of the Commission's peak power limits as proposed in the *Notice* is that the peak power limit provides the restriction at lower PRFs while the average power limit provides the restriction at higher PRFs. .

[221] Attachments to U.S. Department of Defense filing of 10/1/00.

[222] ARRL employed a receiver noise level of –141 dBm and a noise figure of 3 dB, resulting in a thermal noise floor of –139 dBm, for both 1 kHz bandwidth receivers used in its analyses.

[223] This would be expected with a constant envelope signal level.

practice, the actual received signal levels are typically well above the thermal noise floor of the receiver. ARRL assumed that the UWB transmitter would be operating at an average EIRP of –80 dBm/Hz at 420 MHz or at –90 dBm/Hz at 2500 MHz. The specific limits proposed in the *Notice* were 200 uV/m, as measured at 3 meters with a quasi-peak detector, for 420 MHz and 500 uV/m, as measured at 3 meters with an average detector and a 1 MHz resolution bandwidth, for 2450 MHz. These limits are equivalent to an EIRP of 12 nW/120 kHz[224] or –49.2 dBm/120 kHz or –100 dBm/Hz at 420 MHz and to an EIRP of 75 nW/MHz or –41.25 dBm/MHz or –101.25 dBm/Hz at 2450 MHz. Therefore, the levels ARRL applied to the UWB emissions are 11 to 20 dB higher than those proposed in the *Notice*. We also believe that it is extremely unlikely that the UWB emission would be in the main beam of a 20 dBi gain antenna, particularly given the operating restrictions we are applying to UWB devices.[225] Adjusting ARRL's analyses to take these factors into account substantially reduces ARRL's estimate of the increase in the noise floor of the receivers.

151. In addition, we note that Part 15 devices already operate in the 2400-2450 MHz band used by the amateur radio service at considerably higher power levels that those proposed in the *Notice*. For example, frequency hopping spread spectrum transmitters are permitted to operate at a signal level of 36 dBm/MHz and at even higher signal levels for fixed point-to-point links. Similarly, microwave ovens and other Part 18 devices are permitted to operate on a primary basis within this frequency band without a limit on the level of their emissions. Nevertheless, amateurs have coexisted successfully with these devices. This leads us to conclude that it is unlikely that UWB devices will have any significant impact on Amateur operations in this spectrum. We find nothing in the ARRL analysis that leads us to conclude that the existing Part 15 emissions limits are inadequate to control interference from UWB devices to the Amateur Radio Service.

5. Analyses of Potential Interference to PCS

152. Several parties performed tests and analysis of potential interference to PCS systems operating in the 1850 – 1910 MHz and 1930 -1990 MHz bands.[226] These studies are discussed in the following paragraphs.

153. *Motorola Analysis*. Motorola performed mathematical analyses of potential interference from UWB devices to PCS systems. Motorola bases its definition of harmful interference on a PCS receiver as any signal that causes a 1 dB rise in the receiver thermal noise floor, *i.e.*, resulting from an UWB device that produces signal in the PCS receiver that is 6 dB below the thermal noise floor. Motorola assumed that the receiver would have a 10 dB noise figure and an antenna with –8 dBi of gain. Using free space attenuation, it calculated that the UWB and the PCS receiver must be separated by at least 13 meters. It then demonstrated how this separation distance increased with increasing antenna gain such that the minimum separation distance becomes 65 meters when the receiving antenna gain is increased to +6 dBi, *i.e.*, the antenna employed with a base station.

154. Protecting the PCS receiver to a level 6 dB below the thermal threshold of the receiver is not reasonable because it represents the ideal performance of the receiver and is not representative of

224 At the PRFs commonly employed by UWB transmitters, it is expected that a quasi-peak detector will tend to measure closer to the peak level as opposed to the average level. However, the amateur narrowband receiver would respond to the average level of the UWB emission. This could be considerably less than the peak level. In any event, the devices operating below 1 GHz will be extremely limited in number and scope and should not be a source of interference.

225 While a 20 dBi Yagi antenna is feasible, such an antenna normally would be mounted high above a roof where it is unlikely that a nearby UWB transmitter would be directly in the main beam.

226 It should be noted that the PCS frequency bands are not restricted bands. Part 15 devices currently are permitted to transmit in the PCS bands at a level equivalent to –41.25 dBm/MHz EIRP.

typical operating conditions. In practice, PCS receivers will normally receive signals well above the thermal threshold of the receiver. Thus, Motorola's analysis affects receivers operating at the fringe of a reception area. In addition, it is likely that intervening objects would provide significant attenuation to UWB emissions. Thus, we do not believe that Motorola's calculations provide a reasonable representation of the interference potential of UWB to PCS operations.

155. *Sprint PCS, Time Domain Corporation and Telcordia Analyses.* Sprint PCS and TDC jointly submitted two documents. The first was a theoretical model developed by Telcordia Technologies to analyze the impact of UWB on the forward link on a CDMA PCS network. The second summarized tests conducted by Sprint PCS, Time Domain and Telcordia. These tests included laboratory evaluations, over the air transmissions in an anechoic chamber, and field simulations. The over-the-air test conducted in an anechoic chamber demonstrated the following[227]: (1) free space attenuation is appropriate for this type of test; (2) the PCS handset had an antenna gain of –4.6 dBi;[228] (3) the RSSI measured by the handset was 3 dB different from computed values;[229] (4) the measured E/N for the onset of frame errors was 5 dB, consistent with expectations; (5) the handset power varied by 1.5 to 2.5 dB due to antenna polarization and by 12 to 15 dB use to "head loss", *i.e.*, signal blocking by the user; and (6) the effect of UWB IX appears to be the same as Gaussian noise.[230] Much of the data from the open field tests was lost.[231] The available test data employed an RSSI (total forward power received by the handset) of between –92 dBm and –96 dBm. As only a single test cell was activated, no account was taken of potential interference from other nearby cells. The minimum UWB separation distance to avoid interference at that signal level was found to be about 0.35 to 0.56 meters. The call was dropped when the UWB emitter was moved to within about 0.3 meters of the PCS handset.[232] It also was noted that with a fully loaded system this distance range would apply with the RSSI at about 7 dB greater, *i.e.*, at –85 dBm to –89 dBm. Several comments were filed in response to this test.

156. Sprint PCS stated that these tests confirm that a UWB emission at a level 12 dB below the general limits in 47 C.F.R. § 15.209 will cause interference to a PCS CDMA system, resulting in the handset, operating with a PCS received signal of –100 dBm, requesting 50 percent more power when only 2 meters from the UWB transmitter.[233] It added that a separate effect of UWB interference is call blocking such that if between one in twenty and one in five PCS customers are within 2 meters of active UWB transmitters 2 percent to 7.9 percent of calls will be dropped or call attempts will be blocked.[234]

157. On the other hand, TDC believes that the theoretical model of Telcordia does not accurately describe the results of real world open field testing, adding that it is not possible for the PCS receivers to detect UWB emissions even at separation distances less than 1 meter.[235] It stated that the PCS phone performance was dramatically better in an anechoic chamber than in an open field even

227 *See* Sprint PCS comments of 9/12/2000 at Attachment 2, pg. 2-3.

228 In the anechoic chamber test, it appeared that the antenna was optimized for the transmit band rather than the receive band resulting in a measured gain of –4.6 dBi.

229 Thus, the losses between the antenna and the receiver are greater than those used in the above calculations.

230 Qualcomm stated that for commercial CDMA receivers it does not matter if the in-band noise has spectral lines or is white spectrum; what matters is total power in a 1.2288 MHz bandwidth. *See* Qualcomm comments of 5/10/01 at pg. 14.

231 Sprint PCS comments of 9/12/2000 at Attachment 2, pg. 4.

232 Sprint PCS comments of 9/12/2000 at Attachment 2, pg. 4.

233 Sprint PCS comments of 4/6/01 at pg. 2.

234 Sprint PCS comments of 4/6/01 at pg. 2-3.

235 TDC comments of 4/25/01 at pg. 79.

through the base station was clearly visible to the handset and the propagation path was unobstructed.[236] According to TDC, the model developed by Telcordia predicted that in an anechoic chamber IS-95 cellphones should not experience frame error rates greater than 2 percent at received signals levels as low as –105 dBm; however, in the open field the FER would jump momentarily to as much as 8 percent even when the received signal was as great at –85 dBm. TDC adds that extrapolation from testing suggests that the impact of the UWB emission on PCS might be observable when the PCS signal is marginal, at –95 dBm, and the UWB device is continually transmitting and within 1.5 meters.[237] However, it concluded that this was a conservative estimate since during the open field testing with a PCS received signal level of between –92 dBm and –95 dBm no impact from the UWB emission was seen until the UWB emitter was less than 1 meter from the PCS cellphone.

158. XSI also believes that the earlier Sprint PCS/TDC tests demonstrated that UWB devices would not cause substantial harmful interference to PCS, stating that the claim of interference is based on numerous unrealistic assumptions and conflicting results.[238] XSI stated that it is important to note that the anechoic chamber eliminated all external RF noise and any potential interference due to other CDMA cells or multi-path which it says are the most important factors in understanding potential interference for a PCS network.[239] The test that was performed at an outdoor facility showed that the PCS handset exhibited a rise in traffic channel power and then dropped a call only when a UWB transmitter was moved to within approximately 0.3 meters of the handset.[240] XSI noted that the Sprint model did not consider non-line-of-sight propagation effects, nor did it provide an allowance for interference from other base stations although this effect is shown to be significant, resulting in as much as a 5 dB rise in the effective noise floor.[241] XSI concluded that the live testing by Sprint PCS showed that effects such as interference, noise, and Rayleigh fading were severe enough to mask any effects predicted by the analytical model until the UWB emitter was moved to within approximately 0.3 meters of the PCS handset.[242]

159. We find that the testing in the anechoic chamber permitted the PCS receiver to function properly down to the thermal noise floor of the receiver. Once this equipment was placed outdoors in a simulated environment, the UWB emissions had no significant interference effect except at distances less than one meter. We find that it is extremely unlikely that UWB devices will be located this close to a PCS receiver, particularly given the operating restrictions we are applying to UWB devices. Further, we do not believe it is appropriate to use such a close separation distance as the basis for controlling harmful interference. Any interference at close distances can be easily remedied by moving the devices a short distance apart.

160. *Qualcomm Analysis.* Qualcomm performed a mathematical analysis accompanied by laboratory testing using a PCS simulator. Based on its mathematical analysis, Qualcomm asserts that a PCS mobile unit would need to be at least 24 meters from a UWB transmitter operating at the 47 C.F.R. § 15.209 limit in order not to receive harmful interference. A more detailed discussion of the Qualcomm analysis has been placed in the docket file for this proceeding.

236 TDC comments of 4/25/01 at pg. 83-84.

237 TDC comments of 4/25/01 at pg. 85.

238 XSI comments of 5/10/01 at pg. 4.

239 XSI comments of 5/10/01 at pg. 5-6.

240 XSI comments of 5/10/01 at pg. 6.

241 XSI comments of 5/10/01 at pg. 7-8.

242 XSI comments of 5/10/01 at pg. 11.

161. We observe that Qualcomm's mathematical analysis is based on defining harmful interference as any UWB emission that is greater than 6 dB below the thermal noise floor of the PCS receiver. While such an analysis can determine if a signal will increase the receiver noise floor in situations where no RF background noise exists, this is not indicative of harmful interference to a communications system. Modifying the antenna gain to –4.6 dBi to reflect the measured data from the Sprint analysis, and using free space to recalculate the minimum separation distance necessary to prevent harmful interference to a PCS system, we find that a UWB transmitter must be 3.2 meters from the PCS receiver if the UWB transmitter operates at the limit in 47 C.F.R. § 15.209 and 0.8 meters if the UWB transmitter operates at 12 dB below the limit in 47 C.F.R. § 15.209, as proposed in the *Notice*. These separation distances are based on worst case conditions as they do not assume that there is additional attenuation of the UWB emissions due to intervening objects, mismatched antenna polarizations, head loss, or other effects. They also assume that the UWB transmitter is operating at its maximum emission limit with the emission directed at the PCS receiver.

162. The laboratory measurements performed by Qualcomm demonstrated that a S/I of about a 6 dB is required to prevent interference to a PCS system. We believe that a PCS received signal level of –96 dBm/1.25 MHz adequately characterizes a low level PCS signal level based on real world applications.[243] Using free space analysis, this PCS signal level and a 6 dB S/I for the UWB emission, we find that the UWB transmitter must be 7.2 meters from the PCS receiver if the UWB transmitter operates at the limit in 47 C.F.R. § 15.209 and 1.8 meters if the UWB transmitter were to operate at 12 dB below the limit in 47 C.F.R. § 15.209. Again, these separation distances are based on worst case conditions as they do not assume that there is additional attenuation of the UWB emissions due to intervening objects, mismatched antenna polarizations, head loss, or other effects. They also assume that the UWB transmitter is operating at its maximum emission limit with the emission directed at the PCS receiver.

163. *Summary of findings of analyses of interference to PCS.* Upon review of the various tests and analyses submitted in the record, we do not believe that UWB devices will present a significant risk of harmful interference to PCS, particularly when evaluated under actual operating conditions instead of in a laboratory environment. Nevertheless, given that we are applying a reduction of at least 12 dB in emissions in the GPS frequency band, which is in close proximity to the PCS band, in an abundance of caution we will require this reduction to extend through the PCS band to 1990 MHz. We do not believe this will have any significant impact on the viability of UWB devices. Further, this will ensure against interference to PCS even under extremely close separation distances.

6. Cisco Analysis of Potential Interference to MMDS

164. Cisco presented mathematical analyses to demonstrate that a single UWB transmitter would cause a significant increase to the noise floor of a MMDS receiver located several hundred meters away. Attachment 2 to its comments addressed UWB peak emissions, and Attachment 3 to its comments addressed UWB average emissions. With regard to peak emissions, Cisco calculated, based on the proposal in the *Notice* for a limit on total peak power, that a UWB transmitter operating with a pulse width of one nanosecond and possessing a 1.5 gigahertz –10 dB bandwidth will have a total peak emission 49.4 dB greater than the average limit. It then calculated that for a UWB system to comply with a 49.4 dB peak to average ratio it must operate with a pulse repetition frequency of 11.5 kHz.[244] As this is less than the 12 MHz bandwidth employed by the MMDS receiver, Cisco calculated that the peak power received by the 12 MHz wide receiver will be 44.1 dB greater than the average UWB received power.

243 47 C.F.R. § 24.236 states that the median field strength at any location on the border of the PCS service area shall not exceed 47 dBuV/m. As this is the signal level established in the rules as what is necessary to prevent interference to an adjacent license, it appears likely that PCS systems are designed to operate at this level or higher. For a 50 ohm system, this emission level is equivalent to a received signal level of –96 dBm.

244 No limit on the peak-to-average ratio was proposed in the *Notice*.

165. We find that in calculating the –10 dB bandwidth of the UWB transmitter Cisco assumed the use of a perfect antenna. It is unlikely that an antenna, which acts as a band-pass filter, would pass all of the energy over a 1.5 gigahertz bandwidth centered on the UWB emission. The actual total peak signal, based on the proposal in the *Notice*, may be lower due to the narrower transmitted bandwidth. Cisco also assumed that the UWB transmitter had to meet a peak-to-average ratio whereas our proposal was to establish an average limit and a peak limit with the latter consisting of two parts: a total peak power based on the bandwidth of the emission and a peak power limit based on a 50 MHz bandwidth. In actual practice, a UWB transmitter will be subject to the average limit or to the peak limit but not both. Systems with low PRFs will be governed by the peak limits and systems with high PRFs will be governed by the average limits.

166. With regard to average power levels, Cisco modeled a 2.5 GHz sinusoidal carrier modulated by a one nanosecond pulse with a PRF of 20 MHz. Cisco then assumed that the UWB transmitter operated at the maximum limit and was pointed directly at a 20 dBi antenna employed by the MMDS receiver. Cisco also assumed that its MMDS operation should be protected to at least a level of 10 dB below the thermal noise floor of the MMDS receiver without adjusting the noise floor for line losses and the receiver noise figure. With free space attenuation, this resulted in Cisco calculating a minimum separation distance of 380 meters. Cisco then assumes that 10 or 100 UWB transmitters all are emitting at the maximum allowable emission limit at 2.5 GHz and are all pointed directly at the MMDS antenna to show how, using free space attenuation, the required separation distances increase to 1.2 km and 3.9 km.

167. We find that the protection of the MMDS receiver to a level 10 dB below the thermal threshold of the receiver is not reasonable.[245] Second, we note that the actual thermal noise floor of the MMDS receiver would be higher than that calculated by Cisco once line losses and the receiver noise figure are included. Unfortunately, these values are not provided by Cisco to permit the calculations to be redone. Third, at the distances employed free space is not a practical method to calculate path loss. At these distances, intervening objects would provide significant attenuation to UWB emissions. Fourth, it is extremely unlikely that the UWB emission could be pointed at the main beam of a high-gain MMDS antenna because such antennas generally are mounted outside on roof tops or on the sides of buildings. Because of this antenna placement, it is highly unlikely that a UWB transmitter would be close to an MMDS station or have its emissions directed within the mean beam of the MMDS receiving antenna. As with the SARSAT and FSS stations, MMDS antennas will not be directed at buildings or other structures that would block reception of the MMDS transmissions. We also note that millions of other RF products, such as spread spectrum transmitters operating in the 2400-2483.5 MHz band under the provisions of 47 C.F.R. § 15.247, already are permitted to place spurious emissions in the MMDS bands at the emission level proposed in the *Notice*. The spread spectrum spurious emissions must be attenuated to –41.25 dBm/MHz,[246] the same level proposed for UWB emissions.

7. XM Analysis of Potential Interference to DARS

168. XM performed an analysis of potential interference to its satellite digital audio radio service operating in the 2332.5 – 2345 MHz band. XM stated that its satellite receiver operates with a received signal of –109 dBm to –90 dBm with a noise figure of 1.2 dB and a thermal noise of –110

[245] *See*, for example, *Second Memorandum Opinion and Order* in WT Docket No. 99-168, 16 FCC Rcd. 1239 (2001), at para. 6-8.

[246] This is the limit for emissions appearing within the 2483.5-2500 MHz band. The limit on emissions from spread spectrum transmitters appearing within the MMDS band above 2500 MHz is about +16 dBm but may be higher for high gain antennas used with point-to-point spread spectrum systems.

dBm/2 MHz.[247] XM then calculated, using free space, the required separation distances between a UWB device and a DARS receiver in order to ensure that the UWB emissions are below the thermal noise floor of the DARS receiver. At a level of –41.25 dBm/MHz, XM calculated that the UWB device must be 35 meters from the DARS receiver.[248] XM also stated that the required S/N for its receiver is 3 dB, the I/N is 67 dB and the minimum distance from an interference source must be based on 1 meter. Accordingly, XM requests that the emissions from UWB devices in its 2332.5-2345 MHz band be limited to –70 dBm.

169. As discussed above, harmful interference is not caused to a receiver from a radio signal that is below the thermal noise floor of a victim radiocommunications receiver. If we assume that the UWB signal, emitting at –41.25 dBm/MHz, may not exceed the DARS receiver thermal noise floor of –110 dBm/2 MHz, an attenuation of 71.75 dB is required. Free space at 2340 MHz achieves this attenuation at a separation of around 39 meters. If we take into account the 3 dB loss between XM's circular polarized antenna and the linear polarization expected from UWB operation, the separation drops to 27.9 meters. If only 10 dB of attenuation is applied to the UWB emission, the minimum separation distance decreases to 8.8 meters. This is not an excessive separation distance for a receiving system that generally is expected to be mounted outside of a transportation vehicle or on the roof or side of a building. Under practical operating conditions, there would be further attenuation of the UWB emissions due to the presence of intervening objects, misalignment of the UWB transmitting and DARS receiving antennas, and other factors. Further, the DARS signal normally would be above the minimum received level employed in this calculation. It also is likely that the UWB emissions would be somewhat below the maximum level permitted under the rules. These factors would considerably shorten the calculated interference distance. Vehicle mounted UWB radar systems, which will be located closest to DARS receivers, are being required to operate in a considerably higher frequency band than that used by DARS. This should result in emissions appearing in the DARS band that would be no more of an interference threat than emissions from conventional Part 15 devices.[249] In any event, emissions from the vehicular radar systems would likely be pointed in a direction other than at the DARS antenna. Further, since vehicle manufacturers will provide DARS and UWB radar systems in the same vehicle the vehicle manufacturer would engineer these systems to ensure that there is no mutual interference. We also note that DARS will be supplemented in major metropolitan areas with high powered terrestrial broadcasting stations, further reducing the potential for harmful interference.

8. Summary of Tests and Analyses

170. The protection levels established in this Order primarily are those determined in the NTIA analyses of Government systems. The UWB emissions level NTIA developed for the GPS bands provides a conservative protection level for all of the government and commercial systems operating between 960 MHz and 1610 MHz. We find that the various analyses were generally based on overly conservative and worst case conditions. For example, tests were performed in some cases using UWB signals with characteristics designed to cause the greatest interference effect. While we recognize this could occur, in practice many UWB devices will have emission characteristics that are more benign relative to particular receivers. We also note that several of the analyses seek to protect radiocommunications systems to levels below the receiver thermal noise floor. This is a level of performance that does not generally occur under actual operating conditions due to the presence of other

247 Referencing the thermal noise to 290°K, the receiver noise level for a 2 MHz bandwidth is –110.97 dBm. A thermal noise referenced to 290°K is appropriate as the omnidirectional antenna employed by the DARS receiver will encompass surrounding terrain.

248 Sirius stated that with a typical noise figure of 2 dB, receiver performance would be degraded by 3 dB at 150 feet for line-of-sight and 25 feet for non-line-of-sight. Sirius comments of 4/25/01 at pg. 3.

249 Due to the extremely wide frequency separation, it is likely that emissions in the DARS band would be considerably lower than the Part 15 emission limits.

sources of radio noise. Further, the fact that the noise floor may increase does not necessarily indicate that harmful interference will occur.

171. Certain of the analyses applied only free space attenuation to determine propagation losses and did not consider the effects of intervening objects. Some commenting parties sought to ensure that no interference would occur at unreasonable separation distances, such a having the victim receiver within one meter of, or co-located with, the UWB transmitter. In some cases additional protection margins were added to further ensure conservative protection levels. We observe that these various studies and analyses have been useful in serving to illuminate the record in this proceeding. However, we do not believe our regulations for controlling interference from UWB devices should be based on a series of worst case assumptions. Instead, we find that the various studies demonstrate conclusively that UWB devices can be permitted under the proper set of standards without causing harmful interference to other radio operations.

E. Emission Limits

1. General

172. Proposal. In order to control harmful interference from UWB devices, appropriate emission limits must be established. The current Part 15 rules are based on the equivalent of a power spectral density, *i.e.*, a field strength limit is specified along with a measurement bandwidth. These emission limits were chosen to protect various classes of receivers from interference at certain separation distances. The radiated limits below 1 GHz are based on measurements employing a quasi-peak detector that effectively provides an average reading with some weighting for peak signal levels. The radiated emissions limits for both intentional and unintentional radiators above 1 GHz are based on measurements using an average detector. However, intentional radiators also are subject to a requirement that the total peak levels of emissions above 1 GHz must be no greater than 20 dB above the average limits.[250] Higher peak levels could lead to an increased risk of interference to certain receivers. For example, if the pulse repetition frequency of the UWB signal is much greater than the bandwidth of a receiver, the emission may appear to be random noise, the effect of which is proportional to the average power in the UWB signal within the receiver's bandwidth. However, if the PRF is much less than the receiver's bandwidth, the UWB signal may appear to the receiver as impulsive noise and the effect would be proportional to the peak power of the UWB signal. In addition, UWB devices spread their emissions over a wide bandwidth as compared to most current intentional and unintentional radiators. As a result, receivers that use wide bandwidths are likely to receive more total energy from UWB devices than from most other existing Part 15 devices.

173. In the *Notice*, the Commission concluded that it is necessary to regulate both the peak and average emission levels above 1 GHz and the quasi-peak emission levels below 1 GHz from UWB transmitters, just as it regulates these emission levels for most other types of Part 15 transmission systems. The impact of UWB signals on a receiver appears to depend on the randomness of the UWB signal and the relationship between the pulse repetition frequency (PRF) of the UWB signal and the bandwidth of the receiver.[251] If the UWB pulses are spaced evenly in time and each pulse is exactly the same (as in many radar systems), then classic communications theory shows that the spectrum consists of narrow spectral lines spaced at the PRF. The impact of these signals on a receiver can be modeled by treating each spectral line as a narrowband conventional signal. This gives rise to one possible way to increase protection to GPS receivers from UWB GPR and through-wall imaging devices. Since repetitive

[250] *See* 47 C.F.R. § 15.35(b).

[251] This assumes that the UWB signal is far enough from the receiver that it does not overload the receiver causing nonlinear operation. The peak limits being considered in this proceeding will ensure that receiver overloading is not a concern.

identical pulses are often applicable to GPRs and through-wall imaging devices, the Commission noted that it might be possible for designers to select system parameters to avoid GPS signal bands and thus avoid co-channel interference. It also may be possible to space the UWB signal's spectral lines in places within the GPS band where GPS receivers are less sensitive to interference. Comments were requested on whether this technique is applicable to all types of GPRs and through-wall imaging devices and the cost implication of using a stable frequency reference to ensure the PRF creates a signal avoiding the GPS bands.

174. For UWB communications systems, the emitted spectrum depends on the information being sent. If the information is unchanging, such as a steady string of zeroes in the case of digital information, the transmitted signal may become a set of spectral lines that has different interference potential than the noise-like spectrum that would be produced under normal modulation. Depending on exactly where these spectral lines are, the interference potential may increase. This could be avoided by using scrambler technology, often used in digital wireline and optical communications systems, which prevents long strings of unchanging bits. The Commission sought comment on whether it should require such scrambler technology for UWB communications systems or, alternatively, a performance requirement that would show that the transmitted spectrum remains noise-like in the case of unchanging input data.

175. Comments. The comments generally indicated that the proposal to place spectral lines outside of critical frequency bands should not be implemented. For example, as noted by AOPA doppler shifts due to movements of the GPS satellites and to movements of planes would negate any ability to avoid the GPS band.[252] AOPA added that the frequency stability of the circuitry used to generate the PRF would have to be very stable raising cost concerns. A. Peter Annan stated that this is an impractical solution for GPRs that have low PRFs that make it impossible to space the spectral lines far enough apart to avoid the GPS bands.[253] ARRL noted that selecting PRFs to avoid generating signals in certain bands would add a layer of regulatory complexity that could perhaps be better addressed through other means.[254] On the other hand, Aether Wire indicates that it may be possible for its equipment to avoid the GPS L1 and L2 bands by adjusting the spaces between the impulse doublets and between the impulses in each doublet of its transmission, noting that the oscillation would have sufficient stability through the use of temperature stabilization.[255]

176. With regard to scrambler technology, the comments supported requiring UWB signals to be noise-like in certain bands, particularly GPS. AOPA noted that sufficient dithering or scrambling of the interference signal spectral lines in the instantaneous time or frequency domains would decrease the probability of harmful interference but could increase aggregate interference.[256] Aether Wire stated that a UWB system that lacks coding for channelization is severely limited in its capabilities and that such a system it the only one for which scrambler technology is applicable.[257] It added that a performance requirement that shows that the transmitted spectrum remains noise-like in the case of unchanging input data is appropriate.

177. Discussion. We have come to the conclusion that there is no need to establish design criteria for UWB systems, such as specifying where spectral lines may be placed or requiring the

252 AOPA comments at pg. 13.

253 A. Peter Anan comments at pg. 4.

254 ARRL comments at pg. 14.

255 Aether Wire comments at pg. 11.

256 AOPA comments at pg. 13.

257 Aether Wire comments at pg. 12.

application of scrambler technology. Rather, we believe that we should specify only the emission limits that are necessary to prevent interference to the authorized radio services. It will be up to the manufacturers of UWB devices to determine how they will comply with these standards. A discussion of the emission levels we are adopting follows. As will be noted, we are adopting a requirement to limit the power level of the spectral lines that appear in the GPS frequency bands.

2. Average and Quasi-peak Emission Levels

178. Proposal. The Commission stated in the *Notice* that the Part 15 general emission limits[258] have a long and successful history of controlling interference to other radio operations. However, the general emission limits were never designed to protect against all possibilities of harmful interference. Rather, these limits were designed to protect neighbors from causing interference to each other.[259] These limits were designed as a reasonable compromise to protect the authorized radio services from receiving harmful interference without requiring an analysis of the individual needs of every type of receiver design used in every radio service. The Commission reiterated that it remains committed to protecting the authorized radio services from receiving harmful interference from Part 15 devices, adding that it was especially concerned about protecting radio services used for safety-of-life applications, such as GPS, from such interference. Accordingly, the Commission indicated in the *Notice* that the general emission limits contained in 47 C.F.R. Section 15.209 appear appropriate for UWB operations. These emission limits are already based on a spectral power density, measuring signal level per unit bandwidth.[260] It also proposed that additional protection be provided below approximately 2 GHz for emissions from UWB devices. For emissions from UWB devices other than GPRs and, possibly, through-wall imaging systems, it proposed that emissions that appear below approximately 2 GHz be attenuated by at least 12 dB below the general emission limits. This attenuation below the general emission levels would provide additional protection to the congested spectrum below 2 GHz without affecting the viability of UWB operations. Comments were requested on whether additional attenuation below 2 GHz is necessary. Comments were also sought on whether the proposed reduction in the emission levels should apply to all emissions below 2 GHz or only to emissions below 2 GHz that fall within the restricted bands shown in 47 C.F.R. § 15.205. Comments also were requested on whether UWB devices other than GPRs, and possibly through-wall imaging systems, should be permitted to operate below 2 GHz provided they comply with these reduced emission levels. Finally, the Commission indicated that the emission limits that were proposed in the *Notice* were a reasonable starting point for establishing standards. As equipment continues to be developed and additional experience is gained with this equipment, future changes to the standards would be considered.

179. Comments/Discussion.[261] A considerable number of comments were filed concerning the levels of emissions that should be permitted for UWB transmitters. Most of the comments supported the continued application of quasi-peak limits on radiated emissions below 1000 MHz and of average and

---

258 *See* 47 C.F.R. §§ 15.109(a) and 15.209.

259 While it is possible to establish emission limits that protect a user from his own interference at separation distances on the order of one meter, such limits would significantly add to the cost of all Part 15 devices, including computers, cordless telephones and receivers.

260 Emissions below 1 GHz are measured using a CISPR quasi-peak detector with a resolution bandwidth of 120 kHz ± 20 kHz. Emissions above 1 GHz are measured using a 1 MHz resolution bandwidth. *See* 47 C.F.R. § 15.35.

261 Some of the comments continued to propose that UWB devices be subject to the same emission limits as those applied to Class A digital devices. The Commission considered this issue in the *Notice* and declined to propose it. We find no new information in the comments that would cause us to reconsider. *See Notice*, *supra*, at para. 40.

peak limits on radiated emissions above 1000 MHz.[262] NTIA, however, requested that average and peak emission limits apply to all emissions above 960 MHz. Some commenting parties requested that we implement limits on spectral power density.[263] However, the quasi-peak and average limits currently contained in the Part 15 rules already are based on spectral power densities. For example, the quasi-peak limits for emissions between 30 MHz and 1000 MHz are based on the emissions that appear in a 120 kHz $\pm$ 20 kHz bandwidth. The emission limits above 1000 MHz are based on the emissions that appear in a 1 MHz bandwidth.[264]

180. There was no concurrence in the comments with regard to the emission limits that should be adopted. The ARRL stated that the Part 15 general emission limits have not been adequate to protect all amateur operations; however, it could, with some reluctance, accept the idea that permitting UWB operation at those levels is not much different in kind from the types of operation permitted under the Part 15 rules.[265] It added that the impact on amateur receivers from UWB signals that are noise-like would be determined by the average power present in the victim receiver bandwidth whereas for UWB signals with low PRFs, the noise may appear as impulse and/or multiple discrete signals within the receiver passband where the peak limit would be more important.[266] Lucent also agreed that the proposed peak and average limits were sufficient for interference protection provided average measurements are clarified.[267] On the other hand, parties such as XM requested that the emission levels in the satellite DARS band be reduced to an EIRP of –100 dBW, about 29 dB below the existing Part 15 emission limit.[268] Parties such as Siemens Automotive and others want the Part 15 emission levels increased at the higher frequencies.[269]

181. With the exception of GPR manufacturers, a few comments requested increases in the Part 15 emission levels for UWB devices. MSSI wished to operate with a one watt peak output into a 6 dBi antenna.[270] While MSSI equated its UWB operation to the regulations for spread spectrum operation, the current rules designate specific frequency bands for spread spectrum operation.[271] Implementation of this same power level for operation in other frequency bands was not supported by the earlier test data or comments. Bosch, Saab, Siemens and Valeo requested that the higher frequency bands be permitted increased signal levels due to increased attenuation.[272] We agree that higher attenuation applies to RF emissions as frequency increases and that this may prove to be an acceptable approach to modifying the Part 15 emission limits. However, we do not believe that initial UWB operations should begin with a power increase.

262 *See*, for example, the comments of AOPA at pg. 12, Lucent at pg. 1, and NBAA at pg. 13.

263 *See*, for example, the comments of AT&T at pg. 6 and Cisco at pg. 6-9.

264 *See* 47 C.F.R. § 15.35(b).

265 ARRL comments at pg. 12.

266 ARRL comments at pg. 14.

267 Lucent comments at pg. 1.

268 XM comments at pg. A6 and reply comments at pg. 8.

269 *See*, for example, Bosch reply comments at pg. 3, SME comments at pg. 3, Siemens comments at pg. 2, and MSSI reply comments at pg. 2.

270 MSSI reply comments at pg. 2. Also, MSSI comments of 3/22/01 at pg. 4.

271 *See* 47 C.F.R. § 15.247. The spread spectrum frequency bands are 902-928 MHz, 2400-2483.5 MHz, and 5725-5750 MHz.

272 Bosch reply comments at pg. 4. Saab comments at pg. 3. Siemens comments at pg. 2. Valeo comments at pg. 5-6. Valeo actually requested a variable limit where the emission would be at thermal noise at 10 meters using free space, a 0 dBi antenna and a 3 dB receiver noise figure.

182. As noted by TDC, the issue of what constitutes reasonable levels of emissions outside of defined bands confronts the Commission every time a new licensed or unlicensed service is proposed.[273] However, several tests and analyses, discussed earlier, have been performed in this proceeding that permit us to determine the appropriate emission limits. As noted earlier, there were only a few instances where UWB systems operating at the limits in 47 C.F.R. § 15.209 demonstrated a clear potential to cause harmful interference to the authorized radio services. In most of these instances, the UWB transmitter and the victim receiver were required to be in extremely close proximity to each other before harmful interference could occur.

183. As discussed earlier, the interference analyses performed by NTIA and others allowed us to determine the emission limits that should be applied to UWB devices operating under various worst case conditions. Based on the limited information in the record and our lack of operation experience with UWB devices, we believe it best to proceed with an abundance of caution in establishing emission limits. The limits we are adopting were coordinated with NTIA, as well as with several other U.S. Government agencies.[274] These limits are an appropriate first step in introducing UWB devices. The following table specifies the average emission limits, in terms of dBm EIRP as measured with a one megahertz resolution bandwidth, that we are implementing for UWB operation.

Table 8 Average Emission Limits Applicable to UWB Operation

Frequency Band (MHz)	Imaging below 960 MHz	Imaging, Mid-Frequency	Imaging, High frequency	Indoor applications	Hand held, including outdoor	Vehicular radar
0.009-960	§15.209	§15.209	§15.209	§15.209	§15.209	§15.209
960-1610	-65.3	-53.3	-65.3	-75.3	-75.3	-75.3
1610-1990	-53.3	-51.3	-53.3	-53.3	-63.3	-61.3
1990-3100	-51.3	-41.3	-51.3	-51.3	-61.3	-61.3
3100-10600	-51.3	-41.3	-41.3	-41.3	-41.3	-61.3
10600-22000	-51.3	-51.3	-51.3	-51.3	-61.3	-61.3
22000-29000	-51.3	-51.3	-51.3	-51.3	-61.3	-41.3
Above 29000	-51.3	-51.3	-51.3	-51.3	-61.3	-51.3

184. Mid-frequency imaging, consisting of through-wall imaging systems and surveillance systems, must operate with the –10 dB bandwidth within the frequency band 1990-10,600 MHz. High frequency imaging systems, equipment that will be operated exclusively indoors, and hand held UWB devices that may operate anywhere, including outdoors and for peer-to-peer applications, must operate with the –10 dB bandwidth within the frequency band 3100-10,600 MHz. All other imaging systems must operate with the –10 dB bandwidth below 960 MHz. Vehicular radar systems must operate with the -10 dB bandwidth within the frequency band 22-29 GHz and with a carrier frequency greater than 24.075 GHz. To further ensure that the operation of these UWB devices does not result in harmful interference, we also are requiring coordination with NTIA through the Commission of the imaging systems. The operators of these devices will be required to provide us with their address, the characteristics of the UWB device, and a detailed record of the areas in which the equipment will be operated. The information submitted to the Commission will be forwarded to NTIA for notification purposes. The operators of UWB imaging systems must complete this coordination and authorization procedure before initial operation of the equipment in a particular area. As noted previously, in emergency situations a

273 TDC comments at pg. 19.

274 *See* letter of February 13, 2002, from William Hatch, *supra*.

notification process may be used in lieu of coordination.[275] Further, depending on the specific location it may be necessary for the operators to coordinate day-to-day operations with nearby radio stations within their operating area. The manufacturers of these devices will be required to inform the users of the equipment of these requirements. Because of the tighter emission limits being employed, coordination is not being required for indoor equipment, hand held devices, or vehicular radar systems.

3. Imaging Systems Including GPRs

185. As noted throughout this Report and Order, we are taking a cautious approach to the standards for UWB devices. One method of reducing interference potential is to restrict the applications for using UWB devices and the locations where UWB devices may be operated. These devices will have a low proliferation and would be used infrequently. Further, the primary energy from a GPR is directed into, and absorbed by, the ground. In addition, the energy radiated by the GPR is at a low elevation where it should attenuate rapidly.[276] To ensure that the proliferation remains low, we are restricting the parties that may operate GPRs to law enforcement, fire and emergency rescue organizations, to scientific research institutes, to commercial mining companies, and to construction companies. As used in this Order, law enforcement, fire and emergency rescue organizations refers to parties eligible to obtain a license from the FCC under the eligibility requirements specified in Section 90.20(a)(1) of this chapter. All users of GPRs must be eligible for licensing under Part 90 of our rules, and these users must coordinate with the FCC, which in turn will coordinate with NTIA, before operation.

186. Peter Annan stated that GPRs need special consideration on emission limits with more power needed at lower frequencies, particularly for operation below 250 MHz.[277] He requested that GPRs be permitted to operate at an average power limit of 500 mW below 50 MHz and 20 mW above 250 MHz with a logarithmic progression between these power levels between 50 MHz and 250 MHz. GSSI and Sensors & Software, in extremely late filed comments, requested that GPRs operating with PRFs lower than 500 MHz and at frequencies below 500 MHz be permitted to exceed the 47 C.F.R. § 15.209 limits, up to a maximum level of 95 dBuV/m below 30 MHz.[278] These companies did not indicate how or at what distance the revised emission limit should be measured, but we believe, based on their October 2, 2001, meeting with the staff of our Office of Engineering and Technology, that they desired these limits to be based on an average measurement.

187. Subsequent to the October 10, 2001, filing by GSSI and Sensors and Software, a late filed comment was submitted on October 16, 2001, by Mr. Steven Koppenjan *et al*, identifying themselves as the general chairs of the 6th, 7th, 8th and 9th International Conferences on Ground Penetrating Radar. Mr. Koppenjan *et al* indicated that new GPR products are being developed that will comply with the limits proposed in the *Notice*. They add that pulse compression schemes can provide both low peak-to-average

275 We note that US Government radio stations may be operated without coordination under emergency circumstances. *See Manual of Regulations and Procedures for Federal Radio Frequency Management*, U.S. Department of Commerce, National Telecommunications and Information Administration, January 2000, at Section 7.3.1. We also note that no similar provision exists that would permit non-Government operation absent appropriate coordination. However, we are implementing a procedure similar to that contained in 47 C.F.R. Section 2.405(a)-(e) to facilitate the emergency operation of UWB imaging devices.

276 We expect that the emissions would attenuate with distance based on the cube of the inverse distance, not the square as employed with free space propagation.

277 A. Peter Annan comments at pg. 3-5.

278 GSSI and Sensors and Software comments of October 10, 2001. The maximum limit was expressed as 20 log (500MHz/testing frequency in MHz) dBuV/m. At, say, 20 MHz, the testing frequency is 9 kHz resulting in a signal level of 94.9 dBuV/m or 55,600 uV/m. The existing limit at 20 MHz is 30 uV/m, as measured at 30 meters with a quasi-peak detector, or 29.5 dBuV/m.

power ratios in the time domain and low spectral power density in compliance with the proposals.

188. Sufficient notice was not provided to the other parties interested in this proceeding to permit us to address a relaxation to the emission limits below 500 MHz. In addition, the request to allow certain GPR devices to operate at higher emissions levels was filed very late, which did not afford an opportunity for analysis by other parties. We also note that GSSI did not provided any interference analysis to support its proposals, other than a statement that existing GPRs have operated benignly with these emission characteristics for 30 years. It appears that the basis of the proposals from GSSI and from Sensors & Software is to accommodate existing equipment designs.[279] It also appears, based on the comment from Mr. Koppenjan *et al*, that it may be possible for GPRs to be designed to comply with the radiated emission limits proposed in the *Notice*. Thus, we are not persuaded that higher emission levels are prudent especially in the early stages of UWB standards development. Such higher limits could overpower the front end of a nearby receiver or result in harmful interference to nearby television broadcast reception.

189. In contrast to GPRs, other types of imaging systems may be used for a variety of applications where the energy is aimed horizontally along the earth. We anticipate that the walls, buildings or other objects against which the imaging system may be placed may absorb most of the energy.[280] However, we recognize that with imaging systems other than GPRs there is an increased risk that some of the energy would not be absorbed and could be radiated in the direction of authorized radio services. Thus, as a cautious approach we are restricting the use of imaging systems. Wall imaging systems may be employed only by law enforcement, fire and emergency rescue organizations, by scientific research institutes, by commercial mining companies, and by construction companies. Only law enforcement, fire or emergency rescue organizations may use through-wall imaging systems. Further, the operators of through-wall and wall imaging systems must be parties that are eligible to obtain licensing under the provisions in Part 90 of our rules. Finally, medical imaging systems may be used only at the direction of, or under the supervision of, a licensed health care practitioner. This will allow the introduction of the compelling uses for UWB imaging systems cited by the commenters, such as for hostage rescue, law enforcement, inspection of building walls and foundations, and detecting objects inside walls when performing construction. At the same time, by limiting the applications for UWB imaging we will minimize the risk of interference by controlling the proliferation of these devices. The applications for UWB imaging systems will be controlled through our equipment authorization program. In addition, the grantees of equipment authorization will be responsible for ensuring that the marketing and distribution of these products is consistent with the restrictions on use.

4. Other Applications

190. While we believe that some of the interference levels characterized by the commenters may not represent real-world situations, we agree that the initial UWB regulations should be implemented cautiously. Accordingly, we are implementing a reduction to the Part 15 general emission levels over certain frequency bands to ensure that our introduction of UWB devices causes the least possible impact to the authorized radio services. We investigated different standards for UWB devices depending on whether they are operated outdoors or indoors. We believe that the combined operating conditions and emissions standards will prevent harmful interference. The operation of UWB devices at the EIRP levels

279 The only UWB GPRs that have been certified by the Commission are those produced by U.S. Radar. U.S. Radar received a waiver from the Commission, subsequent to extensive coordinated with NTIA, to permit the marketing and use of its product. The marketing or use of any GPR that has not been certified, except under the conditions specified in 47 C.F.R. § 15.211, is in violation of 47 U.S.C. 301 and 302 and is subject to the penalties described in 47 U.S.C. 501-510.

280 Similarly, we believe that medical imaging systems would be used indoors such that intervening walls would attenuate the emissions.

being adopted in this proceeding should provide sufficient attenuation to protect authorized services from harmful interference from UWB systems operating nearby or in elevated locations, such as inside buildings.

191. With regard to GPS, we are particularly concerned about protecting E-911 applications. As noted above, GPS systems can experience harmful interference if they are within a few meters of a UWB system operating at the general limits in 47 C.F.R. § 15.209. The emission limits being adopted in this proceeding within the GPS frequency bands, ranging from 12 to 34 dB below the Part 15 general limits, were found to be more than sufficient to protect GPS from harmful interference. Further, we note that GPS operates in the same frequency region as DME transponders, the ARSR-4, and SARSAT systems.[281] We also note that the emission limits we are applying to the GPS bands are more than sufficient to prevent harmful interference to all Government systems operating in the 960-1610 MHz band.

192. We also concluded from our analysis of the Qualcomm submission that it could be advantageous to provide additional protection to PCS operation in the 1850-1990 MHz band due to its potential use in E-911 applications. The 12 dB of attenuation below the Part 15 general emission limits appears more than sufficient to provide this protection, as described in our discussion of the Qualcomm analyses. We do not believe that additional attenuation is needed for UWB emissions falling in the Cellular Radiotelephone Service bands at 824-849 MHz and 869-894 MHz bands. In the first place, the Part 15 general emission limits for the cellular frequency band, unlike those for the PCS band, are expressed as a quasi-peak limit. The modulation employed by UWB devices will tend to be measured in the cellular band as a peak spectral power density whereas the cellular receiver will respond to the average signal level from the UWB transmitter. This should provide sufficient additional protection to cellular reception. Second, only imaging systems will operate at the low frequency employed for cellular operation. Third, the emissions from cellular transmitters that fall within the band used by the mobile receiver are permitted at a level of –80 dBm, as measured at the antenna connector.[282] This is the level of interference that a cellular mobile transmitter may cause to its own receiver. This also is the level that would be produced by a UWB transmitter, operating at the Part 15 general emission limits, at a separation distance of about 4 meters using free space attenuation with no intervening objects. Thus, the separation distance between a UWB transmitter operating at the general emission limits and a cellular receiver is about the same as that of a UWB transmitter operating at 12 dB below the general emission limits and a PCS receiver. Accordingly, we find that no additional attenuation in the cellular band is required.

193. Based on the above, we are applying a 12 dB reduction below the general emission limits over the frequency range 1610 MHz to 1990 MHz.[283] We also have applied a 10 dB reduction below the general emission limits for emissions between 1990 and 3100 MHz to ensure protection from harmful interference to the U.S. Government operations within this band as well as the operation of DARS and other communications systems operating within this band.

194. One of the largest potential outdoor uses of UWB technology is vehicular radar. However, we do not believe that the proliferation of such devices will result in increased interference

281 GPS operation occurs at 1164-1215 MHz for the L5 band, 1215-1240 MHz for the L2 band, and 1559-1610 MHz for the L1 band. DME transponders operate at 1025-1150 MHz; the ARSR-4 operates at 1240-1370 MHz; and SARSAT operates at 1544-1545 MHz.

282 47 C.F.R. § 22.917(f). This standard originally was established by the cellular industry, working through the Electronics Industry Association, and was published in the Commission's OST Bulletin No. 53, *Cellular System Mobile Station – Land Station Compatibility Specification*, April 1981 at Section 2.2.3.1.1.

283 As discussed elsewhere in this Order, an additional 8 dB of suppression has been applied to vehicular radar systems and an additional 10 dB has been applied to hand held devices at the request of NTIA.

concerns at the emission levels and frequency range being adopted. We are requiring that the -10 dB bandwidth be between 22-29 GHz and that the center frequency be greater than 24.075 GHz.[284] In addition, there is a high probability that other intervening objects, *e.g.*, other vehicles, will cause the emissions to rapidly attenuate, especially at the higher frequencies. Emissions far removed from the center frequency, *e.g.*, emissions appearing below 10 GHz, should appear similar to spurious emissions from other types of Part 15 devices.[285] Because we are requiring the lower frequency emissions to be attenuated below the Part 15 general emission limits, the interference potential from vehicular radar systems to lower frequency radio systems will be less than the interference potential of conventional Part 15 devices.

195. Our primary interference concern with vehicular radar systems is cumulative interference to passive sensing systems operating in the 23.6 to 24.0 GHz band on low earth orbiting satellites, including meteorological satellites.[286] NTIA indicated that it performed an analysis of the potential interference to EESS passive satellite receivers.[287] NTIA states that a potential for harmful interference to EESS receivers would exist if emissions below 24.0 GHz were permitted at the Part 15 general emission limits. NTIA based its analysis on a 22 to 23 dB antenna discrimination at elevation angles above 30 degrees above the horizon. It concluded that the emissions from vehicular radar systems in the 23.6-24.0 GHz band must be 35 dB below the Part 15 general emission limits at elevation angles greater than 30 degrees above the horizon.[288] NTIA indicated that an attenuation of 25 dB at elevation angles of greater than 30 degrees could be achieved at the present time. NTIA indicated that the radars would be placed on transportation vehicles over a period of time and agreed to allowing a phased-in approach to obtain the additional attenuation. It agreed to permit UWB vehicular radar systems provided these systems attenuate emissions appearing within the 23.6-24.0 GHz band at greater than 30 dB elevation above the horizontal plane by the following amounts below the Part 15 general emission limits: 25 dB by January 1, 2005; 30 dB by January 1, 2010, and 35 dB by January 1, 2014.

196. We believe that the analysis performed by NTIA may be overly conservative.[289] However, to ensure that the cumulative impact of the potentially tens of thousands of transportation vehicles employing these radar devices does not result in harmful interference to the passive satellite receivers we are requiring that the emissions 38 degrees or higher above the horizontal plane in the 23.6-24.0 GHz band from properly installed vehicular radar systems be attenuated by more than 25 dB below

[284] Part 15 radar systems currently are permitted to operate in the 24.075-24.175 GHz band. *See* 47 C.F.R. § 15.245.

[285] The UWB antenna will act as a band-pass filter. Emissions appearing, say, 20 GHz below a transmitter operating with a center frequency above 24 GHz will be a random collection of cabinet radiation and antenna resonant frequencies.

[286] *See 47 C.F.R. § 2.106.*

[287] *See* letter of February 13, 2002, from William Hatch, *supra.*.

[288] We note that it does not make a difference as to whether this attenuation is achieved through antenna directivity, the suppression of emissions below 24 GHz or some other method.

[289] For example, NTIA did not provide any attenuation of the radiated emissions due to foliage, terrain, buildings, or other vehicles as would be expected at the low elevation angles involved. NTIA also assumed that each vehicle would have four radar transmitters directed towards the satellite, resulting in a 6 dB increase to the received level, with the emissions from these transmitters attenuated, due to antenna directivity, by 21.9 dB at an angle of 33.2 degrees, the lowest LOS elevation angle used in NTIA's analyses. NTIA concluded in its calculations that an additional 10 dB of attenuation is necessary, resulting in an antenna directivity of 31.9 dB at 33.2 degrees above the horizontal plane, of 33.2 dB at 35.2 degrees, or of 40 dB at 90 degrees, depending on which of its four analysis NTIA employed. However, NTIA then required that the antenna directivity be increased to an even tighter margin of 35 dB at an elevation of 30 degrees. NTIA did not provide any justification for its additional protection margin.

the Part 15 general emission limit. The attenuation can be due to antenna directionality, a lowered transmitter power level or whatever combination produces this desired result. For equipment authorized, manufactured or imported on or after January 1, 2005, this attenuation below the Part 15 general emission limit must be increased to 25 dB at 30 degrees or greater elevation. This attenuation at elevations greater than 30 degrees shall increase to 30 dB by January 1, 2010, and to 35 dB by January 1, 2014. We intend to review these standards as additional experience is gained. In addition, we note that this limit on the emissions from a vehicular radar in the vertical direction results in the emissions radiated towards the passive satellite sensors to appear as spurious emissions. Thus, we are exempting Part 15 UWB devices from the provisions contained in US Footnote 246 to the frequency allocation table.[290]

197. We were able to reduce considerably the potential for harmful interference from UWB systems by limiting outdoor devices to imaging and vehicular radar applications. These devices will likely use directional antennas that reduce the probability that a UWB transmitter will be pointed at any particular victim receiver. However, the UWB proponents indicated a desire to provide many other types of UWB systems, especially communications systems. These systems likely would operate at high PRFs with omnidirectional antennas in the lower frequency bands, *e.g.*, with a center frequency lower than 5 to 7 GHz. Further, manufacturers indicated their desire to permit these operations with minimal restrictions on who may use the equipment or on licensing. Indeed, some proponents requested that we establish an emission limit that permits general outdoor operation.

198. XSI, in its *ex parte* filing of October 22, 2001, among others, requested that we prohibit outdoor infrastructure or establish lower emission limits to permit outdoor applications.[291] XSI stated that it would be willing to attenuate the emissions from its UWB communications systems to below the Part 15 general emission limits by 12 dB over the band 2 GHz to 1.6 GHz, 18 dB below 1.6 GHz, and 35 dB in the GPS band with an additional 10 dB in the GPS band for spectral lines. In its *ex parte* filing of November 5, 2001, XSI suggested that the Commission require an additional reduction of 9 to 12 dB in emissions below 3.1 GHz from peer-to-peer devices to provide the same attenuation that would be provided indoor operation due to building shielding.[292]

199. Based on our coordination with NTIA and other concerned U.S. Government agencies, we believe that limited outdoors operation, including general peer-to-peer operations, can be permitted provided the emissions from the UWB devices within the 1610-3100 MHz band and above 10.6 GHz are attenuated by at least 10 dB below the emission levels being permitted for indoor applications. However, we remain concerned that permitting UWB devices to be used outdoors could result in the development of large communications systems that could adversely impact the authorized services. For that reason, we are prohibiting the use of antennas attached to outside structures or any form of fixed outdoor infrastructure. To further prevent use of these products as fixed outdoor systems, we are requiring that these devices be hand held products. Further, to ensure that these products do not emit energy when they are not transmitting information to an associated receiver, we are requiring that hand held UWB devices be designed to cease transmission within ten seconds unless an acknowledgment is received from the associated receiver that the transmission is being received. This acknowledgment of reception must continue to be received by the UWB transmitter at least every ten seconds in order for the UWB transmitter to continue transmission. This will ensure that the UWB device transmits only when it is sending information to an associated receiver. Finally, to further limit the proliferation of these products

290 *See 47 C.F.R. § 2.106.*

291 Prior XSI comments indicated that UWB operation would be restricted to indoor systems. *See*, for example, XSI reply comments at pg. 5 where XSI states that indoors only operation should be required until the Commission has developed a full technical record.

292 NTIA acknowledged building attenuation levels of 9 dB from 960-3000 MHz, 12 dB from 3000-5650 MHz, and 14 dB from 5650-7250 MHz. *See* NTIA Special Publication 01-43, *supra*, at pg. 5-31.

we are prohibiting the use of UWB devices for the operation of toys.[293] We believe that these conditions reflect our desire to proceed cautiously with the introduction of UWB equipment.

200. Except for toys, we are permitting indoor systems to be used for any type of application, including communication systems, provided emissions are not intentionally directed outside, *e.g.*, through a window or doorway to perform an outside function such as the detection of persons about to enter a building. We also are prohibiting the use of fixed outdoor antennas, such as antennas mounted on the side or top of a building, or other outdoors infrastructure. The −10 dB UWB bandwidth, encompassing both the center frequency of operation and the frequency at which the highest radiated emission occurs, must be greater than 3.1 GHz. This will remove the highest emission level components away from the more sensitive radio services operating below this frequency. Building shielding combined with the emission limits being adopted should prevent interference to the authorized services, including the indoor operation of cellular, PCS and GPS systems employed in E-911 applications.[294] However, because indoor systems will be permitted to operate at higher emission levels than outdoor systems, we find that we must adopt a regulation that states that the UWB equipment, by the nature of its design, must be capable of operation only indoors. If a manufacturer were to design a system that permits peer-to-peer operation to function only indoors, we will permit it. An example would be where peer-to-peer operation can occur only when an emission from an associated base station also is detected. A necessity to operate with a fixed indoor infrastructure also may be sufficient to demonstrate indoors only operation. This action is consistent with the method we used with unlicensed PCS to ensure that portable devices were not introduced into areas that had not yet been cleared of existing licensed users.[295]

201. We also note that TDC expressed specific interest in permitting the use of UWB for surveillance systems.[296] These are radar devices that establish a stationary RF perimeter field, similar to that of a half-bubble, that is used for security purposes to detect the intrusion into a designated area by persons or objects. We believe that TDC's request has merit but remain concerned about the potential for the proliferation of these devices. Accordingly, we are requiring the same coordination procedures that we applied to imaging devices. In addition, we are limiting the operation of surveillance systems to law enforcement, fire and emergency rescue organizations, to public utilities and to industrial entities. These parties must be eligible for licensing under Part 90 of our rules.

5. Emission Levels above 1990 MHz

202. We previously discussed the analyses of potential interference to U.S. Government radio operations, amateur operation at 2450 MHz, MMDS operation around 2500 MHz, and satellite DARS at 2320-2345 MHz. The comments also addressed concerns regarding possible harmful interference to several other radio operations. AT&T requests that additional attenuation be provided as high as 2600 MHz to protect possible future 3G operations and also requests that UNII operation at 5 GHz be protected.[297] Lucent also requests additional protection for future 3G systems.[298] Motorola lists several

[293] This is consistent with our desire to proceed cautiously with the introduction of UWB devices. This is an area that we may wish to readdress in our further review of the UWB standards that is scheduled to occur in the next six to twelve months.

[294] Requiring the equipment to be operated indoors also should provide an effect similar to that of a directional antenna. RF emissions would not be directed skyward due to increased rooftop attenuation. Variable attenuation of the building walls and attenuation by randomly placed objects within the building will reduce the probability that emissions radiated from the building will be pointed in any particular direction.

[295] 47 C.F.R. § 15.307.

[296] *See*, for example, TDC's *ex parte* filing of November 20, 2001.

[297] AT&T comments at pg. 7-8. UNII systems operate under Part 15 and are not entitled to protection from interference. *See* 47 C.F.R. § 15.5.

operations above 2 GHz that should be protected from UWB operations, such as 3G, MDS, WCS, and others, but does not provide any information to demonstrate that UWB devices operating on these frequencies would be a problem.[299]

203. We note that the 10 dB of attenuation below the Part 15 general emission limits that are being provided in the frequency range of 1990-3100 MHz to protect various U.S. Government radio operations appears to be more than sufficient to protect non-Government operations from harmful interference. The only UWB operations not subject to this additional 10 dB of attenuation are through-wall imaging systems used by public safety organizations and surveillance systems employed by public safety organizations and by public utilities and industrial entities. As used in this Order, the reference to public utilities and industrial entities refers to the manufacturers licensees, petroleum licensees or power licensees defined in 47 C.F.R. § 90.7. We believe that the requirement for surveillance systems to operate at the Part 15 general emission limits in combination with the coordination procedures are sufficient to alleviate concerns of harmful interference.

204. Except for imaging devices operating below 960 MHz, through-wall systems, surveillance systems and vehicular radars, all other UWB devices are being required to operate with their −10 dB bandwidth between 3.1-10.6 GHz. Above 3.1 GHz, it appears that the Part 15 general emission limits are sufficient to protect the various authorized radio services from harmful interference. The upper frequency limit of 10,600 MHz provides additional protection to the passive satellite receiving system frequency band at 10,600-10,700 MHz. Only vehicle radar systems are being permitted to operate with their -10 dB bandwidth between 22-29 GHz. Further, as requested by NTIA we are requiring that unwanted emissions from vehicle radar systems be attenuated 20 dB below the Part 15 general limits if they are outside the 22-31 GHz band and 10 dB below the Part 15 general limits if they are in the band 29-31 GHz. The filing from SARA indicated that their equipment could comply with such an emission limit.[300]

6. Dithering and Other Noise-Like Emission Requirements

205. As discussed earlier, the measured level at which interference occurred to a GPS C/A code receiver was 8 dB lower for a CW-like UWB emission than that at which interference occurred from a noise-like UWB emission. This 8 dB difference is in agreement with the international standards, which specify that CW-like emissions necessitate 10 dB of additional interference protection.[301] Because a CW-like emission consists of narrow spectral lines, the standard is specified as the signal level contained within a 700 Hz bandwidth.

206. We concur with the test data and international standards that an additional 10 dB of protection should be provided to GPS emissions from CW-like, narrowband emissions produced by the UWB transmitter. However, we note that a 700 Hz bandwidth setting is not available on the measurement instrumentation, such as a spectrum analyzer. XSI agreed with USGPSIC that this 10 dB of suppression could be demonstrated using a 10 kHz resolution bandwidth.[302] We also agree that a 10 kHz resolution bandwidth could be used to demonstrate that the CW-like emissions are suppressed 10 dB

(...continued from previous page)

298 Lucent comments at pg. 7.

299 Motorola comments at pg. 36. While Motorola in its comments requested that UWB systems be required to attenuate emissions 12 dB below the Part 15 general limits, it later requested that 18 dB of attenuation be required but supplied no data to support its request. Motorola reply comments at pg. 2 and 7.

300 *See*, for example, the *ex parte* comments of December 5, 2001, from DaimlerChrysler and SARA on pg. 14.

301 Recommendation ITU-R M.1477, *supra*.

302 XSI comment of 7/25/01responding to the USGPSIC comment of 6/21/01.

below the limits applicable to noise-like emissions.[303] However, we wish to specify the measurement bandwidth as close as possible to the specification employed in the ITU-R recommendation. While a 700 Hz resolution bandwidth is not available, the use of a 1 kHz resolution bandwidth is adequate for this measurement. A CW-like emission will have the same emission level whether it is measured with a 1 kHz, a 10 kHz or a 1 MHz resolution bandwidth. Thus, we are requiring the average emissions appearing within the GPS frequency bands, 1164-1240 MHz and 1559-1610 MHz, when measured with a resolution bandwidth of no less than 1 kHz, to be attenuated by 10 dB below the average limit specified for a 1 MHz resolution bandwidth, *i.e.*, the noise-like emission limit. Specifying the resolution bandwidth for the CW-like measurement as no less than 1 kHz permits noise-like UWB systems to be tested with a wider bandwidth so that testing time may be reduced.[304]

7. Emissions from Incorporated Digital Devices

207. We note that many UWB transmission systems will incorporate digital devices that, by themselves, will radiate RF emissions. We also note that requiring the emissions from these digital devices to comply with some of the reduced levels being adopted in this proceeding may make production infeasible. We see no reason, based on the submissions in this proceeding, that emissions from associated digital circuitry should be required to have any greater attenuation than required under the current rules. To do so may make it technically infeasible or overly expensive to design UWB devices. However, we note that the digital circuitry used with a transmitter for the purpose of enabling the operation of the transmitter is not defined as a digital device but is considered to be part of the transmitter. Thus, this digital circuitry would normally be subject to the emission limits applicable to the transmitter. Under the current rules, emissions from digital circuitry used to enable the operation of the transmitter are not required to be reduced below the general limits in 47 C.F.R. § 15.209. We see no reason to change this existing provision. Accordingly, we are permitting the emissions from digital circuitry used to enable the operation of an UWB device to operate at the limits contained in 47 CFR § 15.209 provided it can be clearly demonstrated that those emissions are due solely to emissions from the digital circuitry and are not intended to be radiated from the antenna. We are not addressing distinctions between Class A and B digital devices as this is not considered in the current regulations. However, if the digital circuitry is used to control additional functions or capabilities, *i.e.*, it complies with the definition in 47 C.F.R. § 15.3(k) for a digital device, that aspect of the digital circuitry may comply with the standards for a Class A digital device or a Class B digital device, as applicable, in accordance with the current rules.

8. Peak Emission Limits

208. Proposal. In the *Notice*, the Commission noted that the peak output level does not directly impact the interference seen by a narrowband receiver. It is the power spectral density of the pulse and the pulse repetition frequency that are important for controlling potential interference. However, a limit on peak emissions is necessary to reduce the potential for UWB emitters to cause harmful interference to radio operations above 1 GHz. The Commission proposed two methods of measuring peak emission levels: 1) the peak level of the emission when measured over a bandwidth of 50 MHz which is comparable to the widest victim receiver that is likely to be encountered, and 2) the

303 If the signal is noise-like, the reduction from a 1 MHz resolution to a 10 kHz resolution bandwidth would cause a 20 dB reduction in the measured signal level.

304 A true CW-like emission will have the same measured emission level regardless of the resolution bandwidth provided only one spectral line is contained within the bandwidth of the measuring instrument. A true noise-like emission will change by 10 dB for every 10 percent change in the measurement bandwidth, *i.e.*, a signal measured to be –30 dBm with a 1 MHz resolution bandwidth will be –60 dBm when measured with a 1 kHz resolution bandwidth. When noise-like and CW-like emissions are mixed, as with most UWB operations, the measured UWB emission will decrease logarithmically with the decrease in resolution bandwidth until the imbedded CW emissions begin to be detected and resolved.

absolute peak output of the emission over its entire bandwidth. Comments were requested on the suitability of these two measurements with regard to the potential for interference from UWB transmitters to wideband receivers used in the licensed radio services.

209. In the case of the first definition of peak level, *i.e.*, the peak signal strength measured over a 50 MHz bandwidth, the Commission proposed to apply a 20 dB limit with respect to the maximum permitted average emission level.[305] This limit is consistent with the limit currently contained in 47 C.F.R. § 15.35(b). It also proposed that the absolute peak limit for the emission over its entire bandwidth be variable based on the amount the –10 dB bandwidth of the UWB emission exceeds 50 MHz. The Commission proposed to use the following formula to calculate the amount that the absolute peak emission level over the entire bandwidth of the UWB emission would be permitted to exceed the Part 15 average emission limit: $[20 + 20\log_{10}(-10 \text{ dB bandwidth of the UWB emission in Hertz}/50 \text{ MHz})]$ dB with the further stipulation that the absolute peak emission level not be permitted to exceed the average limit by more than 60 dB.[306] This 60 dB limit is comparable with the limit permitted under the waivers recently issued to Time Domain Corporation, U.S. Radar Inc. and Zircon Corporation.[307] Comments were requested on whether wideband receivers used in the licensed services are sensitive to peak signal level in a unit bandwidth, such as the 50 MHz referenced above, or to the total peak emission produced by the USB device, and whether both peak limits are needed to reduce potential interference to the authorized radio services. If only one peak limit is needed, the comments should indicate which limit is appropriate. The Commission indicated that it intended to rely heavily on submitted test data in determining what peak emission standards should apply to UWB products.

210. The Commission requested comments as to whether the higher absolute peak limit will cause increased interference problems, especially using the proposed measurement procedures and the limitations on frequency bands of operation. Comments were requested on the proposed method of varying the absolute peak emission limit and whether other features, such as the excess bandwidth, *i.e.*, the amount of the occupied bandwidth/effective data rate exceeds a specified level such as 10 dB, should be employed in calculating a peak limit.

211. Comments. Several of the comments agreed with our specifying a peak limit over a 50 MHz bandwidth. As stated by AOPA, 50 MHz is ample for current GPS, GLONASS and AMS(R)S receivers which have a front end bandwidth of about 30 MHz.[308] NBAA agreed that a 50 MHz bandwidth is appropriate for protection of the current radio services.[309] AOPA and NBAA noted the possibility that wider bandwidths may be needed in the future if UWB is found to have operational and spectrum efficiency advantages that make it desirable for use in aeronautical communications. Similarly, Valeo Electronics stated that the proposal to measure peak over 50 MHz is appropriate and comparable to the worst case of a likely victim receiver.[310] It also noted that adoption of this standard would make it

[305] The average limit above 1000 MHz, 500 uV/m, as measured at 3 meters, is equivalent to an equivalent isotropically radiated power (EIRP) of –41.25 dBm/MHz. Thus, the proposed peak limit in a 50 MHz band would be 5000 uV/m, as measured at 3 meters, or –21.25 dBm/ 50 MHz EIRP. It appears that several of the commenters mistakenly believed that the Commission proposed to apply a limit to the peak-to-average ratio of the UWB transmission instead of to the peak emission level.

[306] This would be equivalent to a total peak EIRP of +18.75 dBm.

[307] *See* waivers issued on June 29, 1999, by the Chief, Office of Engineering and Technology. While the waivers stated that the maximum peak-to-average ratio was limited to 30 dB, these ratios were calculated using $10 \log_{10}[(\text{pulse width}) \times (\text{pulse repetition frequency})]$ dB. For conventional pulses, the calculation would have been based on a $20 \log_{10}$ factor, resulting in a maximum 60 dB peak-to-average ratio.

[308] AOPA comments at pg. 14.

[309] NBAA comments at pg. 15.

[310] Valeo Electronics comments at pg. 11.

unnecessary to specify a limit on the total peak signal level. TDC also objected to a limit on total peak signal level as it would be relevant only to receivers that have a bandwidth wide enough to receive the entire UWB transmission.[311] Nortel noted that future software-defined receivers will use wider bandwidths and that a 50 MHz bandwidth would not seem unreasonable in a few years.[312] Bosch also agreed that a 50 MHz bandwidth was a practical standard for a wideband receiver.[313]

212. ANRO requested a limit on the total peak level, noting that peak measurements over a 50 MHz BW would be difficult and citing an uncertainty as to where in the spectrum 50 MHz measurements should be made.[314] On the other hand, Kohler noted that the proposal to establish an absolute peak limit based on the bandwidth of the UWB transmission would encourage manufacturers to employ as wide a bandwidth as possible in order to increase the peak limit and result in greater UWB intrusion into a broader range of frequencies.[315] SiRF Technology, Inc. & Trimble Navigation request that peak power be measured on a "per-nanosecond basis."[316] USGPSIC also requested that peak power be measured on a "per nanosecond basis" believing that otherwise UWB devices would be permitted to emit peak power levels in excess of a megawatt.[317] XSI noted that the calculation by USGPSIC requires the use of an impractical PRF of 1 second and that the average level employed by USGPSIC is 50 dB higher than that proposed in the *Notice* for emissions in the GPS band.[318]

213. The commenters did not agree on the peak signal limit that should be employed. TDC, noting that the absence of peak limits would allow UWB systems operating at low PRFs to emit enormous pulse levels, stated that it was not clear how a 50 MHz measurement bandwidth and a limit of 20 dB above the average limit were indicative of interference potential and that there was no justification provided for these values.[319] TDC later requested that the peak power in a 50 MHz band be limited to 0 dBm EIRP.[320] Kohler notes that its system operates at an average level of –47.3 dBm/MHz and a total peak signal of +7 dBm.[321] XSI stated that its equipment operates with a 5 dB peak to average ratio.[322] CSSIP requested that a peak limit apply below 1000 MHz.[323] This limit, as measured in a 6 MHz bandwidth, would be 20 dB greater than the quasi-peak limit.

214. Discussion. There are two reasons for imposing a peak emission limit on UWB devices.

311 TDC comments at pg. 34.

312 Nortel comments at pg. 4.

313 Bosch comments at pg. 5.

314 ANRO comments at pg. 2. ANRO also requested peak limits of 2 kW for UWB systems using directional antennas.

315 Kohler comments at pg. 5-6.

316 SiRF Technology, Inc. & Trimble Navigation joint reply comments at pg. 3.

317 USGPSIC comments at pg. 41-42. The USGPSIC stated that this high power would occur from the use of a 1 mW average UWB transmission using a pulse width of 1 nS.

318 XSI reply comments at pg. 6.

319 TDC comments at pg. 32-33.

320 TDC comments of 3/12/01 at pg. 17.

321 Kohler reply comments at pg. 2.

322 XSI reply comments at pg. 5. It appears that the 5 dB peak to average applies to average and peak measurements over the same 1 MHz bandwidth.

323 CSSIP comments at pg. 2. We note that the quasi-peak measurement closely approximates the peak level of a pulsed emission. Accordingly, we see no reason to apply a peak limit on top of a quasi-peak limit.

The first, and most obvious, is to keep from overloading the front end of a nearby victim receiver. For example, the interference protection level for C/A-code GPS receivers from low duty cycle pulse-like emissions is +20 dBm peak pulse power at the receiver input.[324] This is considerably higher than the signal levels we are considering in this proceeding. The second reason is because pulsed emissions with low PRFs have high peak-to-average ratios and victim receivers will respond to the peak signal level produced by the UWB transmitter if their bandwidth is wider than the UWB PRF. Thus, we need to address the potential total peak power that will be received in the bandwidth employed by the victim receiver. The total peak power produced by the UWB device is not relevant to interference potential as there are no receivers employed with the authorized radio services that operate at the bandwidths employed by UWB emissions. For that reason, we are not adopting a limit on total peak power. The comments generally agreed that 50 MHz is about the widest bandwidth that would be employed by victim radio receivers. Thus, there appears to be no reason to measure peak power across a wider bandwidth.

215. The low proliferation, infrequent operation, operation near the ground, rapid attenuation of emitted signals, and general operation in the presence of surrounding objects that would further attenuate the emissions should result in a low interference potential from GPRs and other imaging systems.[325] Vehicular radar systems operate above 24 GHz where the emissions will attenuate rapidly with distance and there is a high probability of intervening objects further attenuating the UWB emissions and reducing the probability of harmful interference. We expect that most indoor and hand held systems would operate at high PRF levels, resulting in potential victim receivers reacting only to the average emission levels produced by the UWB devices. However, some UWB devices may be designed to operate at a low PRF with a resulting high peak-to-average ratio. This could result in the peak power level being a controlling factor in potential interference to other receivers. Accordingly, we believe that a peak limit is needed to ensure that nearby victim receivers are not affected.

216. In the *Notice*, the Commission proposed a peak power limit in a 50 MHz band equal to 20 dB greater than the maximum permitted average limit. The average limit is 500 uV/m, as measured at 3 meters with a 1 MHz resolution bandwidth. This is equivalent to an EIRP of –41.25 dBm/MHz.[326] Thus, the peak power limit proposed in the *Notice* was equivalent to an EIRP of –21.25 dBm/50 MHz. The comments generally did not address interference at the peak limits being considered. Because of this, we performed our own analysis on the effect of peak power to a generic communications receiver.[327] We found that a suitable peak EIRP power limit for a transmitter placed 3 meters away would be –33.7 dBm/MHz. For a transmitter placed 10 meters away, the peak EIRP limit would be –23.3 dBm/MHz. We also note that the peak limit needs to be applied at only one location, *i.e.*, centered on the frequency at which the highest level emission occurs.[328]

217. As noted in the section on Measurement Procedures, we find that peak measurements based on a 50 MHz (resolution) bandwidth may not be feasible. The widest readily available resolution bandwidth that can be employed for peak measurements is 3 MHz. Consequently, we prepared a comparison of the differences in peak-to-average ratios, based on an average signal measured with a 1 MHz resolution bandwidth (RBW), as the PRF of the UWB emission and the RBW of the measuring

324 NTIA Special Publication 01-45, *supra*, at pg. 4-3.

325 We also note that many GPRs and imaging systems will operate below 1000 MHz where they are subject to a quasi-peak emission limit. The quasi-peak emission limit should closely approximate the peak levels produced by these devices.

326 There is a direct correlation between EIRP and field strength. Field strength in dBuV/m at 3 meters equals EIRP (in dBm) plus 95.2.

327 Our initial analysis of the effect on a QPSK system has been placed in the docket file for this proceeding.

328 The bandwidth of the measuring instrument would be centered on this frequency.

instrument are varied.[329] These graphs, shown in Appendix E to this Report and Order, compare emissions from conventional pulsed transmissions and dithered (Gaussian) pulsed transmissions.

218. As shown in the graph, the peak EIRP signal level of –21.25 dBm/50 MHz [330] that was proposed in the *Notice* results in non-dithered pulsed emissions being average-limited if the PRF is greater than 11.11 MHz and all dithered UWB emissions being peak-limited.[331] If the RBW is reduced to 3 MHz, the relationship is based on a 20 log factor resulting in a decrease in the peak level allowed with a 50 MHz RBW by 24.44 dB. This results in an allowable peak level of –45.69Bm/3 MHz, a level that is 4.44 dB lower than the permissible average limit with a 1 MHz RBW. Reducing this further to measurement with a 1 MHz RBW lowers the permissible peak level to –55.23 dBm/MHz, 14 dB below the average limit. In actual practice, we would not specify a peak level lower than the average limit. It should be noted that a conventional pulsed modulated emission would not have a peak emission higher than the average limit at PRFs greater than the RBW employed divided by 0.45.

219. Based on the above, we believe that our proposal to permit a peak emission within a 50 MHz RBW of only –21.25 dBm EIRP is too conservative. We believe that the peak emission level of 0 dBm/50 MHz, equivalent to 58 mV/m at 3 meters, requested by TDC would not result in harmful interference problems to communications systems. This level translates to a peak EIRP of –24.44 dBm/3 MHz or 3.6 uW/3 MHz, or to a peak field strength of 3.46 mV/m at measured at 3 meters with a 3 MHz RBW. This peak level is 16.8 dB higher than the average level determined with a 1 MHz RBW and is 3.2 dB lower than the peak limit permitted under the current Part 15 rules. [332] It results in dithered and non-dithered UWB emissions being average-limited for PRFs greater than 1 MHz and peak-limited for PRFs below 1 MHz.

220. Our conversion from a 50 MHz resolution bandwidth to a 3 MHz resolution bandwidth is based on the worse case assumption that changes in the peak levels changes follow the square of the change in the resolution bandwidth. That is, the change in the allowable peak limit at 50 MHz to a peak limit at 3 MHz was based on 20 log (3/50) dB. We recognize that this could penalize some UWB operations, particularly those operating with PRFs greater than around 6.7 MHz. According, we are adopting a peak limit based on a sliding scale dependent on the actual resolution bandwidth employed in the measurement. The peak EIRP limit being adopted in this Report and Order is 0 dBm when measured with a resolution bandwidth of 50 MHz and 20 log (RBW/50) dBm when measured with a resolution bandwidth ranging from 1 MHz to 50 MHz. RBW is the resolution bandwidth, in megahertz, actually employed. The minimum resolution bandwidth that may be employed is 1 MHz; the maximum resolution bandwidth that may be employed is 50 MHz.

---

329 The formulas needed to perform this analysis are contained in NTIA Special Publication 01-43, *supra*, at pg. D-1 through D-2.

330 This equates to a 20 dB peak-to-average level for the 50 MHz RBW curve.

331 "Average-limited" means that the average emission level will be the determining standard on whether the equipment complies with the standards. If the emissions from the device meet the average limit, they will also meet the peak limit. "Peak-limited" is the counter to this where if the device meets the peak limit, it will also comply with the average limit. However, it must be noted that the graphs are based on ideal pulse characteristics. Because of extraneous emissions, *e.g.*, emissions from an associated digital device, antenna effects, different pulse shapes, and other factors it remains necessary to specify both peak and average emissions.

332 The peak limit above 1000 MHz is 5 mV/m. This is equivalent to –21.25 dBm EIRP. *See* 47 C.F.R. §§ 15.33(b) and 15.209. However, it must be remembered that the peak limit in the current Part 15 rules is based on the total peak emission level and not on a peak level over a specified bandwidth.